#13

MAIL DATE CANCELLED

OIPE MAR 0 8 2001 PATENT & TRADEMARK OFFICE

THE UNITED STATES PATENT AND TRADEMARK OFFICE

OIPE JC109 MAR 0 7 2001 PATENT & TRADEMARK OFFICE

In re application of: Rashmi K. Shah, et al.	§ §	
	§	GROUP ART UNIT 1744
Serial No. 09/168,770	§ §	Examiner: F. Varcoe, Jr.
Filed: October 8, 1998	§ §	February __, 2001
FLAMELESS COMBUSTOR PROCESS HEATER	§ §	

ASSISTANT COMMISSIONER FOR PATENTS
Washington, D. C. 20231

AFFIDAVIT UNDER C. F. R. 1.132

I, ANDREAS N. MATZAKOS, being duly sworn, depose and state as follows:

I am an employee of Shell International Exploration and Production, Inc., an affiliate of Shell Oil Company, a corporation organized and existing under the laws of the state of Delaware, having a place of business at One Shell Plaza, 910 Louisiana, Houston, TX 77252.

RECEIVED MAR 12 2001 TC 1700 MAIL ROOM

I have a degree in chemical engineering from National Technical University in Athens, Greece, and a Ph. D. in chemical engineering from Rice University in Houston, TX.

I began working for Shell Development Company in 1991 as an Associate Research Engineer in the area of reaction engineering, with experience in reaction kinetics, reactor modeling and optimization, process development, design and scale-up, and reactive hazards assessment. I officially joined Shell International Exploration and Production, Inc. the beginning of this year.

I have worked with the inventors of the process described in above-identified U. S. Patent Application Ser. No. 09/168,770 and am very familiar with that process and its applications.

I modified a rigorous reactor model written in FORTRAN with thousands of lines of code to predict how intermediate reheat with Flameless Distributed Combustion (Hereafter referred to as FDC) tubes inside a reactor would affect the first reactor stage conversion and capacity. This model, named STYRENE, accounts for homogeneous and heterogeneous kinetics, diffusional limitations, catalyst deactivation, and pressure drop. The model performs heat and mass balances in each reactor stage and the preheat zones. The model can also regress pilot or plant

data to determine best kinetic parameters. R. Hawthorn developed the model 20 years ago at Shell's Westhollow Technology Center and it has been improved by L. A. Clomburg and myself. This is an established model used, for example, by Criterion Catalyst Company to make plant performance predictions.

I used the model to predict how intermediate reheat with FDC tubes inside the reactor, as described in Claim 1 of Ser. No. 09/168,770, as applied to the manufacture of styrene, as described beginning at page 12, last two lines of the application, would affect first stage conversion and capacity.

I found that the increase of the conversion was from 40.1% to 58.5%, leading to ca. 46% higher first stage capacity, and only 12% less than the two-stage conventional train. This result indicates that the second reactor which ordinarily achieves a cumulative conversion of 66.5% would not be necessary, since the capacity of the first stage with FDC tubes would approach the total capacity of the conventional reactors.

A copy of the input file for the reactor model is attached as Exhibit A. (Input file for styrene FORTRAN model). Exhibit B is data for the profile of the reactors.

Model results for an isothermal reactor are attached as Exhibit C and model results for a non-isothermal reactor are attached as Exhibit D. Exhibit E describes input on membrane design, mass and heat balances, however in the STYRENE model no hydrogen was actually removed from the process side of the modeling; therefore, the elements present were representative of the use of the process of Ser. No. 09/168,770 as an oxidation reaction chamber in the production of styrene.

I modeled two adiabatic radial flow reactors (notional segments) with the same length of 11.57m and the ID and OD's of (1.6, 2.5) m and (2.5, 3.14) m respectively, with reheat to the same inlet temperature of 608°C.

```
        Geometry data for the modeled reactor is as follows:Table 1
Number reactor stages = 2
Unit = LG Chemical Korea
Reactor types:
1= Isothermal, axial 2= adiabatic, axial 3= adiabatic, radial

 Press
description
```

					bed dimensions, cm				
Reactor Numb	Reactor type	Catalyst number	Catalyst activity	Bed void fraction	Bed length, cm	bed inner radius, cm	bed outer radius, cm	bed inlet vol, m^3	
1	3	6	1.000	.370	1157.	80.	125.	9.49	
2	3	6	1.000	.370	1157.	125.	157.	0.00	

I summarized the key data in the following table:

Exhibit B:Table 2

Radial Reactor Case	**1st stage conversion and STY selectivity**	**2nd stage conversion and STY selectivity**	**Number of 1 inch tubes needed**	**Percent of equilibrium constant (1st, 2nd)**
1. Adiabatic (no H2 removal)	40.14% w/ 97.39%	**66.46%** w/96.71%	NA	24.1%, 18.9% (no equil. limit)
2. Adiabatic with mid-volume reheat (no H2 removal)	**58.49%** w/ 97.22% (35.3% in the first half of the volume)	Not done	33-214 (optimistic vs. current)	41.7%, NA
3. Adiabatic with mid-volume reheat (with H2 removal)	Model does not allow, but greater than #2	Not done	>33-214	30.1%, NA
4. Isothermal (no H2 removal)	**79.42%** w/ 95.24%	87.67% w/93.56%	57-370 (optimistic vs. current)	61.6%, 53.1% (closer to equil. limit; max =100%)
5. Isothermal (with H2 removal)	Model does not allow, but greater than #4	Model does not allow, but greater than #2	>57-370	32.7%, 50.4% (further from limit)

The process of Ser. No. 09/168,770 used in the production of styrene provides surprising results and overwhelming advantages which would not have been apparent to one skilled in the art by observing Minet el al. in view of Mikus.

The reaction model shows that when the FDC of Ser. No. 09/168,770 is employed in an endothermic reaction the following surprising results are observed:

1) Improved selectivities and/or yields;

2) Reduced byproducts due to uniform heat input;

3) Reduced hot spots due to the use of FDC;

4) Elimination of interstage reheats, thus enabling operation at optimum temperature;

5) Even temperature profiles with respect to materials of construction;

6) Permits the reactor to function essentially isothermally;

7) Permits a considerably higher average temperature because reactor tubes are of uniform temperature.

I was also able to calculate that the modeled reactor can potentially run near isothermally and achieve at least twice or greater the capacity of conventional styrene reactors in one pass. This is demonstrated in Table 2 in which the conversion of the first stage is 79.4% or 98% higher capacity than the conventional one-stage. When compared with the conventional two-stage train, the capacity is still 20% higher, with some small reduction of 2.17% in styrene selectivity. This result again confirms that the second reactor, which ordinarily achieves a cumulative conversion of 66.5%, would not be necessary, since the capacity of the first stage, with the FDC tubes securing isothermal operation, would exceed by 20% the total capacity of the two conventional reactors.

I am also closely involved with the business aspects of this technology and would respectfully assert that further evidence that Ser. No. 09/168,770 would not have been obvious to one skilled in the art observing Minet el al. in view of Mikus is that the Washington Group, formerly Raytheon found that the technology was improved over any similar technology available in the art and filled a distinct need in the art; and, the Washington Group has entered into an exclusive license with Shell to use said technology.

This Affidavit is made with the knowledge that the United States Patent Office will rely on information contained therein, and that willful false statements are punishable by fine or imprisonment or both, under §101 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application at bar or any patent issuing thereon.

ANDREAS N. MATZAKOS

STATE OF TEXAS §
§
COUNTY OF HARRIS §

Sworn to and subscribed before me this 29 day of January, 2001.

Notary Public in and for
Harris County, Texas

SHIRLEY A. TEZANO
Notary Public, State of Texas
My Commission Expires 12-18-2001

Exhibit A


```
Styrene Catalyst Input File
Cataly035    LGC Plant Data
16                               Rxr-Volu
Laboratory data table            Oil dens         Inlet %w composition
gas added,Rxr Performance                                    Weight Factor Matrix
Days oReactorPressureInlet teWater adOil flow  EB    Styrene    Tol
Ben   inert   CO   H2Rxr lenEB ConvS(styreS(tolueS(benzeTgut, CEB
ConS(toluS(benzTgut, Sum (se
00     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0    0.00     0.0      0.0     0.0      0.0  628.3     1
0      0     1     0.0
00     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0 455.50     37.2     98.3     1.2      0.5  559.4
1      1     1   100.0
00     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0    0.00    37.2      0.0     0.0      0.0  631.7     1
0      0     1     0.0
00     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0 375.20     63.7     97.5     1.9      0.6  581.7     1
1      1     1   100.0
10     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0    0.00     0.0      0.0     0.0      0.0  628.3     1
0      0     1     0.0
10     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0 455.50     36.9     98.2     1.2      0.6  559.4     1
1      1     1   100.0
10     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0    0.00    36.9      0.0     0.0      0.0  631.7     1
0      0     1     0.0
10     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0 375.20     63.0     97.8     1.8      0.4  581.1     1
1      1     1   100.0
20     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0    0.00     0.0      0.0     0.0      0.0  628.3     1
0      0     1     0.0
20     1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0 455.50     35.7     98.2     1.3      0.6  559.8
1      1     1   100.0
20     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0    0.00    35.7      0.0     0.0      0.0  632.8
0      0     1     0.0
20     2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0 375.20     61.9     97.7     1.7      0.6  581.3     1
1      1     1   100.0
105    1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0    0.00     0.0      0.0     0.0      0.0  628.3     1
0      0     1     0.0
105    1          10.10    608.0    1.70 42200.0    98.97     0.40      0.41
0.02   0.0   0.0  0.0 455.50     35.9     97.9     1.4      0.7  561.7     1
1      1     1   100.0
105    2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0    0.00    35.9      0.0     0.0      0.0  633.3     1
0      0     1     0.0
105    2           7.30    608.0    0.00      0.0    0.00     0.00      0.00
0.00   0.0   0.0  0.0 375.20     62.0     97.5     1.8      0.6  581.9     1
1      1     1   100.0
123    1          11.17    628.3    1.40 42200.0    96.23     1.25      0.45
0.32   0.0   0.0  0.0    0.00     0.0      0.0     0.0      0.0  628.3     1
0      0     1     0.0
123    1          10.68    628.3    1.40 42200.0    96.23     1.25      0.45
0.32   0.0   0.0  0.0   30.00    35.7     98.1     1.2      0.7  560.7     1
```

```
1     1     1  100.0
123   2          7.09   633.9    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0   0.00   35.7    0.0     0.0     0.0  633.9     1
0     0     1    0.0
123   2          6.15   633.9    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0  30.00   61.6   97.7     1.7     0.6  581.8     1
1     1     1  100.0
154   1         11.21   628.9    1.41127120.0   96.15     1.22     0.45
0.29  0.0   0.0  0.0   0.00    0.0    0.0     0.0     0.0  628.9     1
0     0     1    0.0
154   1         11.21   628.9    1.41127120.0   96.15     1.22     0.45
0.29  0.0   0.0  0.0  30.00   35.6   97.9     1.3     0.8  562.1     1
1     1     1  100.0
154   2          7.15   634.4    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0   0.00   35.6    0.0     0.0     0.0  634.4     1
0     0     1    0.0
154   2          7.15   634.4    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0  30.00   61.5   97.6     1.7     0.7  582.3     1
1     1     1  100.0
169   1         11.46   629.4    1.48125758.0   96.90     1.04     0.35
0.30  0.0   0.0  0.0   0.00    0.0    0.0     0.0     0.0  629.4     1
0     0     1    0.0
169   1         11.46   629.4    1.48125758.0   96.90     1.04     0.35
0.30  0.0   0.0  0.0  30.00   37.5   97.7     1.4     0.9  558.4     1
1     1     1  100.0
169   2          7.40   635.1    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0   0.00   37.5    0.0     0.0     0.0  635.1     1
0     0     1    0.0
169   2          7.40   635.1    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0  30.00   66.0   96.8     2.2     1.0  580.6     1
1     1     1  100.0
193   1         11.37   629.4    1.41126210.0   95.92     1.40     0.46
0.34  0.0   0.0  0.0   0.00    0.0    0.0     0.0     0.0  629.4     1
0     0     1    0.0
193   1         11.37   629.4    1.41126210.0   95.92     1.40     0.46
0.34  0.0   0.0  0.0  30.00   34.9   98.1     0.8     1.1  563.6     1
1     1     1  100.0
193   2          7.32   635.0    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0   0.00   34.9    0.0     0.0     0.0  635.0     1
0     0     1    0.0
193   2          7.32   635.0    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0  30.00   61.3   97.2     1.8     0.9  583.6     1
1     1     1  100.0
216   1         11.34   630.0    1.40126210.0   96.63     1.30     0.45
0.29  0.0   0.0  0.0   0.00    0.0    0.0     0.0     0.0  630.0     1
0     0     1    0.0
216   1         10.78   564.3    1.40126210.0   96.63     1.30     0.45
0.29  0.0   0.0  0.0  30.00   35.3   97.8     1.3     0.9  564.3     1
1     1     1  100.0
216   2          7.22   635.6    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0   0.00   35.3    0.0     0.0     0.0  635.6     1
0     0     1    0.0
216   2          6.21   583.4    0.00      0.0     0.00     0.00     0.00
0.00  0.0   0.0  0.0  30.00   60.3   97.2     1.9     1.0  583.4     1
1     1     1  100.0
```

Exhibit B


```
      Profiles for reactor bed number    1
 No Temp  Press   Concentrations, gmole/kg total feed    -----
Effectiveness factors -----
step DC     Psia    EB     Styrene   Toluene   Benzene   EB = Sty  EB =
Ben  Sty = Tol Sty = CO2
  0 607.6 10.10 3.451E+00 2.079E-02 1.753E-02 2.138E-03
  1 593.8 10.02 3.183E+00 2.833E-01 2.146E-02 3.340E-03 1.782E-01
1.809E-01 1.306E+00 1.322E+00
  2 583.7  9.95 2.989E+00 4.737E-01 2.385E-02 4.203E-03 3.263E-01
3.325E-01 1.037E+00 1.047E+00
  3 576.4  9.88 2.850E+00 6.096E-01 2.555E-02 4.819E-03 4.427E-01
4.518E-01 9.761E-01 9.828E-01
  4 571.1  9.82 2.749E+00 7.097E-01 2.688E-02 5.276E-03 5.288E-01
5.403E-01 9.585E-01 9.636E-01
  5 567.0  9.76 2.670E+00 7.867E-01 2.798E-02 5.631E-03 5.936E-01
6.068E-01 9.534E-01 9.575E-01
  6 563.6  9.70 2.607E+00 8.483E-01 2.892E-02 5.917E-03 6.435E-01
6.579E-01 9.527E-01 9.561E-01
  7 560.9  9.65 2.555E+00 8.991E-01 2.975E-02 6.155E-03 6.830E-01
6.983E-01 9.536E-01 9.566E-01
  8 558.6  9.60 2.511E+00 9.420E-01 3.050E-02 6.358E-03 7.149E-01
7.307E-01 9.552E-01 9.577E-01
  9 556.5  9.56 2.473E+00 9.789E-01 3.119E-02 6.534E-03 7.410E-01
7.573E-01 9.569E-01 9.592E-01
 10 554.8  9.51 2.440E+00 1.011E+00 3.181E-02 6.689E-03 7.629E-01
7.793E-01 9.587E-01 9.607E-01
 11 553.2  9.47 2.411E+00 1.040E+00 3.240E-02 6.828E-03 7.813E-01
7.979E-01 9.604E-01 9.622E-01
 12 551.8  9.43 2.384E+00 1.065E+00 3.294E-02 6.953E-03 7.970E-01
8.137E-01 9.620E-01 9.636E-01
 13 550.5  9.40 2.361E+00 1.088E+00 3.345E-02 7.067E-03 8.107E-01
8.274E-01 9.634E-01 9.650E-01
 14 549.4  9.36 2.339E+00 1.109E+00 3.394E-02 7.172E-03 8.225E-01
8.392E-01 9.648E-01 9.662E-01
 15 548.3  9.32 2.319E+00 1.129E+00 3.440E-02 7.268E-03 8.330E-01
8.496E-01 9.661E-01 9.674E-01
 16 547.4  9.29 2.301E+00 1.146E+00 3.484E-02 7.358E-03 8.422E-01
8.587E-01 9.673E-01 9.685E-01
 17 546.4  9.26 2.284E+00 1.163E+00 3.526E-02 7.441E-03 8.504E-01
8.669E-01 9.684E-01 9.695E-01
 18 545.6  9.23 2.268E+00 1.178E+00 3.566E-02 7.519E-03 8.578E-01
8.741E-01 9.694E-01 9.705E-01
 19 544.8  9.20 2.253E+00 1.192E+00 3.604E-02 7.592E-03 8.644E-01
8.807E-01 9.703E-01 9.714E-01
 20 544.1  9.17 2.240E+00 1.205E+00 3.642E-02 7.662E-03 8.704E-01
8.866E-01 9.712E-01 9.722E-01
      Profiles for reactor bed number    2
 No Temp  Press   Concentrations, gmole/kg total feed    -----
Effectiveness factors -----
step DC     Psia    EB     Styrene   Toluene   Benzene   EB = Sty  EB =
Ben  Sty = Tol Sty = CO2
  0 608.0  7.30 2.240E+00 1.205E+00 3.642E-02 7.662E-03
  1 600.8  7.26 2.102E+00 1.339E+00 3.904E-02 8.278E-03 4.030E-01
4.269E-01 8.736E-01 8.804E-01
  2 595.4  7.22 1.998E+00 1.440E+00 4.114E-02 8.748E-03 4.736E-01
5.019E-01 8.895E-01 8.949E-01
  3 591.2  7.19 1.917E+00 1.520E+00 4.291E-02 9.123E-03 5.299E-01
5.617E-01 9.020E-01 9.064E-01
  4 587.7  7.15 1.851E+00 1.584E+00 4.444E-02 9.431E-03 5.755E-01
6.100E-01 9.119E-01 9.157E-01
  5 584.8  7.12 1.796E+00 1.637E+00 4.579E-02 9.692E-03 6.130E-01
```

```
6.496E-01 9.199E-01 9.232E-01
  6 582.4  7.09 1.749E+00 1.682E+00 4.701E-02 9.916E-03 6.443E-01
6.825E-01 9.265E-01 9.293E-01
  7 580.3  7.06 1.709E+00 1.721E+00 4.812E-02 1.011E-02 6.708E-01
7.101E-01 9.319E-01 9.344E-01
  8 578.4  7.02 1.673E+00 1.755E+00 4.915E-02 1.029E-02 6.934E-01
7.336E-01 9.365E-01 9.387E-01
  9 576.8  6.99 1.642E+00 1.785E+00 5.010E-02 1.045E-02 7.129E-01
7.538E-01 9.404E-01 9.424E-01
 10 575.3  6.97 1.614E+00 1.812E+00 5.099E-02 1.059E-02 7.299E-01
7.712E-01 9.438E-01 9.456E-01
 11 573.9  6.94 1.589E+00 1.836E+00 5.183E-02 1.072E-02 7.448E-01
7.865E-01 9.468E-01 9.484E-01
 12 572.7  6.91 1.566E+00 1.858E+00 5.262E-02 1.084E-02 7.580E-01
8.000E-01 9.494E-01 9.509E-01
 13 571.6  6.88 1.545E+00 1.878E+00 5.338E-02 1.095E-02 7.697E-01
8.119E-01 9.517E-01 9.531E-01
 14 570.6  6.85 1.526E+00 1.896E+00 5.410E-02 1.105E-02 7.802E-01
8.225E-01 9.537E-01 9.551E-01
 15 569.6  6.83 1.508E+00 1.913E+00 5.479E-02 1.115E-02 7.897E-01
8.320E-01 9.556E-01 9.568E-01
 16 568.8  6.80 1.492E+00 1.929E+00 5.545E-02 1.124E-02 7.982E-01
8.406E-01 9.573E-01 9.584E-01
 17 567.9  6.78 1.476E+00 1.943E+00 5.608E-02 1.133E-02 8.060E-01
8.483E-01 9.588E-01 9.599E-01
 18 567.2  6.75 1.462E+00 1.957E+00 5.669E-02 1.141E-02 8.131E-01
8.554E-01 9.602E-01 9.612E-01
 19 566.5  6.73 1.449E+00 1.970E+00 5.729E-02 1.149E-02 8.196E-01
8.618E-01 9.615E-01 9.625E-01
 20 565.8  6.71 1.436E+00 1.981E+00 5.786E-02 1.156E-02 8.256E-01
8.677E-01 9.627E-01 9.636E-01
      Profiles for reactor bed number    1
 No Temp  Press  Concentrations, gmole/kg total feed    -----
Effectiveness factors -----
step DC    Psia    EB     Styrene   Toluene   Benzene   EB = Sty  EB =
Ben  Sty = Tol Sty = CO2
  0 607.6 10.10 3.451E+00 2.079E-02 1.753E-02 2.138E-03
  1 594.0 10.02 3.188E+00 2.783E-01 2.124E-02 3.317E-03 1.843E-01
1.869E-01 1.326E+00 1.342E+00
  2 584.1  9.95 2.997E+00 4.655E-01 2.352E-02 4.165E-03 3.315E-01
3.374E-01 1.047E+00 1.057E+00
  3 577.0  9.88 2.861E+00 5.994E-01 2.514E-02 4.772E-03 4.465E-01
4.553E-01 9.827E-01 9.893E-01
  4 571.7  9.82 2.760E+00 6.983E-01 2.641E-02 5.223E-03 5.318E-01
5.427E-01 9.632E-01 9.682E-01
  5 567.6  9.76 2.683E+00 7.747E-01 2.747E-02 5.574E-03 5.959E-01
6.085E-01 9.570E-01 9.611E-01
  6 564.3  9.70 2.620E+00 8.359E-01 2.838E-02 5.857E-03 6.455E-01
6.592E-01 9.556E-01 9.590E-01
  7 561.6  9.65 2.568E+00 8.864E-01 2.918E-02 6.093E-03 6.847E-01
6.992E-01 9.561E-01 9.590E-01
  8 559.3  9.60 2.525E+00 9.292E-01 2.990E-02 6.295E-03 7.164E-01
7.314E-01 9.573E-01 9.598E-01
  9 557.3  9.56 2.487E+00 9.660E-01 3.056E-02 6.470E-03 7.424E-01
7.578E-01 9.587E-01 9.610E-01
 10 555.5  9.51 2.454E+00 9.983E-01 3.117E-02 6.624E-03 7.641E-01
7.798E-01 9.603E-01 9.623E-01
 11 554.0  9.47 2.424E+00 1.027E+00 3.173E-02 6.762E-03 7.824E-01
7.982E-01 9.618E-01 9.636E-01
 12 552.6  9.43 2.398E+00 1.052E+00 3.226E-02 6.887E-03 7.981E-01
8.140E-01 9.633E-01 9.649E-01
```

Exhibit C

```
Iteration number          1
k1c=       1061.0000
k2c=          5.3500
k3c=         23.8000
k4c=          1.5800
E1c=      74800.0000
E2c=      74800.0000
E3c=      54700.0000
BK3=         95.0000
BK5=       1100.0000
AK=           1.5000
Sinf=          .3500
kd  =          .0120
1                                      ETHYL BENZENE DEHYDROGENATION PROGRAM
***** REACTOR CALCULATIONS
*****
```


SUMMARY TABLE FOR PREDICTED PERFORMANCE

```
FEED ANALYSIS            % MOLE              % WT
   BENZENE                 .027               .020
   TOLUENE                 .473               .411
   ETHYL BENZENE         99.092             99.168
   STYRENE                 .408               .401

BED 1

   CATALYST
    TYPE                   C-035       (*RELATIVE ACTIVITY =
1.000)
    SIZE(DIA.)          3.30 MM              .130 INCH
   VOLUME
    CATALYST          66.3318 M3        ********* FT3
    HEADSPACE          9.4900 M3        335.09888 FT3
   S/O                  10.01 M/M            1.70 W/W
   LHSV                   .73 V/V-HR          .40 W/W-HR

   T(IN)               608.00 DEGC        1126.40 DEGF
   P(IN)                  .70 BAR           10.10 PSIA
   T DROP                 .26 DEGC            .48 DEGF
   P DROP               .1044 BAR            1.51 PSI
   CONVERSION           79.42 %M            79.42 %W
   SELECTIVITIES
    STYRENE             95.24 %M            93.44 %W
    TOLUENE              3.84 %M             3.33 %W
    BENZENE               .62 %M              .46 %W
```



```
The measured values at   0 days are:
Conversion= 37.20
S(Styrene)= 98.30 S(Toluene)=  1.20 S(Benzene)=   .50
DT(Inlet-Outlet)= 48.60

BED 2

   CATALYST
    TYPE                   C-035       (*RELATIVE ACTIVITY =
1.000)
    SIZE(DIA.)          3.30 MM              .130 INCH
   VOLUME
```

```
 CATALYST         66.1630 M3       ********* FT3
 HEADSPACE        12.6400 M3       446.32769 FT3
S/O                 10.01 M/M           1.70 W/W
LHSV                  .73 V/V-HR         .40 W/W-HR

T(IN)              608.00 DEGC       1126.40 DEGF
P(IN)                 .50 BAR           7.30 PSIA
T DROP                .03 DEGC           .05 DEGF
P DROP              .1610 BAR           2.34 PSI
CONVERSION          87.67 %M           87.67 %W
SELECTIVITIES
 STYRENE            93.56 %M           91.79 %W
 TOLUENE             5.32 %M            4.62 %W
 BENZENE              .70 %M             .52 %W
```

```
The measured values at   0 days are:
Conversion= 63.70
S(Styrene)= 97.50 S(Toluene)=  1.90 S(Benzene)=   .60
DT(Inlet-Outlet)= 26.30

              YIELD                82.02 %M          80.46 %W
1                              ETHYL BENZENE DEHYDROGENATION PROGRAM
***** REACTOR CALCULATIONS
*****
```

SUMMARY TABLE FOR PREDICTED PERFORMANCE

FEED ANALYSIS	% MOLE	% WT
BENZENE	.027	.020
TOLUENE	.473	.411
ETHYL BENZENE	99.092	99.168
STYRENE	.408	.401

BED 1

```
CATALYST
 TYPE                 C-035        (*RELATIVE ACTIVITY =
.926)
 SIZE(DIA.)          3.30 MM            .130 INCH
VOLUME
 CATALYST         66.3318 M3       ********* FT3
 HEADSPACE         9.4900 M3       335.09888 FT3
S/O                 10.01 M/M           1.70 W/W
LHSV                  .73 V/V-HR         .40 W/W-HR

T(IN)              608.00 DEGC       1126.40 DEGF
P(IN)                 .70 BAR          10.10 PSIA
T DROP                .26 DEGC           .47 DEGF
P DROP              .1044 BAR           1.51 PSI
CONVERSION          78.96 %M           78.96 %W
SELECTIVITIES
 STYRENE            95.42 %M           93.61 %W
 TOLUENE             3.68 %M            3.19 %W
 BENZENE              .62 %M             .45 %W
```

```
The measured values at  10 days are:
Conversion= 36.90
S(Styrene)= 98.20 S(Toluene)=  1.20 S(Benzene)=   .60
DT(Inlet-Outlet)= 48.60
```

Exhibit D


```
Iteration number          1
k1c=       1061.0000
k2c=          5.3500
k3c=         23.8000
k4c=          1.5800
E1c=      74800.0000
E2c=      74800.0000
E3c=      54700.0000
BK3=         95.0000
BK5=       1100.0000
AK=           1.5000
Sinf=          .3500
kd   =         .0120
1                      ETHYL BENZENE DEHYDROGENATION PROGRAM
***** REACTOR CALCULATIONS
*****
```


SUMMARY TABLE FOR PREDICTED PERFORMANCE

FEED ANALYSIS	% MOLE	% WT
BENZENE	.027	.020
TOLUENE	.473	.411
ETHYL BENZENE	99.092	99.168
STYRENE	.408	.401

BED 1

CATALYST		
TYPE	C-035	(*RELATIVE ACTIVITY = 1.000)
SIZE(DIA.)	3.30 MM	.130 INCH
VOLUME		
CATALYST	33.5312 M3	********* FT3
HEADSPACE	9.4900 M3	335.09888 FT3
S/O	10.01 M/M	1.70 W/W
LHSV	1.45 V/V-HR	.80 W/W-HR
T(IN)	608.00 DEGC	1126.40 DEGF
P(IN)	.70 BAR	10.10 PSIA
T DROP	63.93 DEGC	115.08 DEGF
P DROP	.0642 BAR	.93 PSI
CONVERSION	1st slice 35.26 %M	35.26 %W
SELECTIVITIES		
STYRENE	97.64 %M	95.79 %W
TOLUENE	1.63 %M	1.42 %W
BENZENE	.55 %M	.40 %W

The measured values at 0 days are:
Conversion= 37.20
S(Styrene)= 98.30 S(Toluene)= 1.20 S(Benzene)= .50
DT(Inlet-Outlet)= 48.60

BED 2

CATALYST		
TYPE	C-035	(*RELATIVE ACTIVITY = 1.000)
SIZE(DIA.)	3.30 MM	.130 INCH
VOLUME		

CATALYST	32.8006	M3	*********	FT3
HEADSPACE	.0000	M3	.00000	FT3
S/O	10.01	M/M	1.70	W/W
LHSV	1.48	V/V-HR	.82	W/W-HR
T(IN)	608.00	DEGC	1126.40	DEGF
P(IN)	.50	BAR	7.30	PSIA
T DROP	42.21	DEGC	75.99	DEGF
P DROP	.0409	BAR	.59	PSI
CONVERSION 2nd slice	58.49	%M	58.49	%W
SELECTIVITIES				
STYRENE	97.22	%M	95.37	%W
TOLUENE	2.04	%M	1.77	%W
BENZENE	.52	%M	.39	%W

The measured values at 0 days are:
Conversion= 63.70
S(Styrene)= 97.50 S(Toluene)= 1.90 S(Benzene)= .60
DT(Inlet-Outlet)= 26.30

YIELD	56.87	%M	55.79	%W

1 ETHYL BENZENE DEHYDROGENATION PROGRAM

***** REACTOR CALCULATIONS *****

SUMMARY TABLE FOR PREDICTED PERFORMANCE

FEED ANALYSIS	% MOLE	% WT
BENZENE	.027	.020
TOLUENE	.473	.411
ETHYL BENZENE	99.092	99.168
STYRENE	.408	.401

BED 1

CATALYST
TYPE C-035 (*RELATIVE ACTIVITY = .926)

SIZE(DIA.)	3.30	MM	.130	INCH
VOLUME				
CATALYST	33.5312	M3	*********	FT3
HEADSPACE	9.4900	M3	335.09888	FT3
S/O	10.01	M/M	1.70	W/W
LHSV	1.45	V/V-HR	.80	W/W-HR
T(IN)	608.00	DEGC	1126.40	DEGF
P(IN)	.70	BAR	10.10	PSIA
T DROP	63.19	DEGC	113.75	DEGF
P DROP	.0642	BAR	.93	PSI
CONVERSION	34.87	%M	34.87	%W
SELECTIVITIES				
STYRENE	97.69	%M	95.84	%W
TOLUENE	1.58	%M	1.37	%W
BENZENE	.55	%M	.41	%W

The measured values at 10 days are:
Conversion= 36.90
S(Styrene)= 98.20 S(Toluene)= 1.20 S(Benzene)= .60
DT(Inlet-Outlet)= 48.60

Exhibit E

Membrane Design - Mass and Heat Balances

Reactor Dimensions	**Stage 1**					
Inner ID	1.6	*m*	5.2493438	*ft*		
Outer ID	3.14	*m*	10.301837	*ft*		
Length	11.57	*m*	37.96	*ft*		
Bed voidage	0.3					
Bed volume	66.33	*m3*	2342.4882	*ft3*	17523.03	*gal*
Bed particle volume	46.43	*m3*	1639.7418	*ft3*	12266.12	*gal*
Packing density	570	*kg/m3*	35.583943	*lb/ft3*		
Particle density	1900	*kg/m3*	118.61314	*lb/ft4*		
Catalyst mass	37809	*kg*	83354.967	*lb*		

Inlet/Outlet Conditions	Inlet				Outlet		
Temperature	608	*C*			567.1	*C*	
Pressure	0.691	*Atm*	10.15	*psia*	0.622	*Atm*	
Oil mass flow rate	11.722	*kg/s*	25.84308	*lb/s*	11.65	*kg/s*	
Steam to oil ratio	1.7	*kg/kg-oil*	10.01	*m/m*			
Steam flow rate	19.9277778	*kg/s*	43.933236	*lb/s*	19.863	*kg/s*	86.17%
Total feed flow rate	31.650	*kg/s*	69.776317	*lb/s*	31.648	*kg/s*	
Vol. Feed flow rate	26.789	*sm3/s*	946.02716	*scf/s*	2515	*l/h*	
Ethyl benzene	99.09%	*%m*	0.1096	*kmol/s*	0.0455	*kmol/s*	3.551%
Styrene	0.41%	*%m*	0.0005	*kmol/s*	0.0628	*kmol/s*	4.902%
Toluene	0.47%	*%m*	0.0005	*kmol/s*	0.0017	*kmol/s*	0.133%
Benzene	0.03%	*%m*	0.0000	*kmol/s*	0.0006	*kmol/s*	0.049%
Total oil	100.00%	*%m*	0.1106	*kmol/s*	0.1106	*kmol/s*	*8.636%*
Hydrogen	0.00%	*%m*	-	*kmol/s*	0.0665	*kmol/s*	5.192%
Equilibrium Πci, K	0.0446	*Πci*	0.1152	*K*	38.7%	*Πci/K*	
With x% H2 removal	0.0321	*Πci*	**29%**	*H2 removal*	27.9%	*Πci/K*	
Mass Performance							
EB Conversion	0.00%	*%in*	58.50%	*%out*	58.50%	*%delta*	
Styrene selectivity	97.22%	*%M*	95.69%	*%W*			
Toluene selectivity	1.84%	*%M*	0.51%	*%W*			
Benzene selectivity	0.94%	*%M*	1.47%	*%W*			
H2 produced	0.06649	*kmol/s*	0.293179	*lb/s*	0.13298	*kg/s*	

Heat performance						
Styrene rxn enthalpy	124808	*kJ/kmol*	53.66	*MBTU/lbmol*	EB->Sty+H2	
Toluene rxn enthalpy	-63385	*kJ/kmol*	-27.25	*MBTU/lbmol*	EB+ 2H2O->Tol+CO2+2H2	
Benzene rxn enthalpy	101809	*kJ/kmol*	43.77	*MBTU/lbmol*	EB+2H2O->Be+CH4+CO2+2H2	
Water heat capacity	2210.7000	*J/kg.K*	0.5280145	*BTU/lb.F*		
EB heat capacity	2780.0000	*J/kg.K*	0.6639889	*BTU/lb.F*		
Sty Heat capacity	2590.0000	*J/kg.K*	0.6186083	*BTU/lb.F*		
Tol Heat capacity	2686.0000	*J/kg.K*	0.6415375	*BTU/lb.F*		
Ben Heat capacity	2570.0000	*J/kg.K*	0.6138314	*BTU/lb.F*		
Heat duty	3137.25232	*kW*	10704.707	*MBTU/h*		
Temperature rise	40.94	*K*	73.695211	*F*	104.49	*K*

Membrane performance						
Max Hydrogen flux neede	0.06470906	*kg/s*	0.1426591	*lb/s*	**49%**	*of produced*
Max Oxygen flux needed	0.51767244	*kg/s*	1.1412726	*lb/s*	0.016177	*kmol/s*
Membrane permeabilty	0.012	*sm3/m2.s.Atm*	0.5	*exponent*		
H2 partial pressure	5.19%	*%m*	0.03228	*Atm*		
Actual Area needed	200.5	*m2*	2158	*ft2*		
Porous tube diameter	0.0254	*m*	0.0833333	*ft*	1	*in*
Area per tube	0.923	*m2*	9.9	*ft2*		
Number of tubes needed	217	*tubes*				